

# STATIC OUT-OF-POSITION TEST METHODOLOGIES: IDENTIFYING A REALISTIC WORST CASE FOR SMALL STATURE FEMALE DRIVERS

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## ABSTRACT

The NHTSA's final interim rule on advanced airbags describes two static out-of-position test procedures for the 5<sup>th</sup> percentile female dummy.

Recent testing by Transport Canada suggests that the procedure described for the positions may not be representative of the worst case condition and may include elements that are not realistic for a 5<sup>th</sup> percentile driver.

A modified positioning procedure which prioritizes chest placement and positions the steering wheel in a location that is compatible with the visibility and comfort requirements of a 5<sup>th</sup> percentile female driver is described. A modified chin on hub procedure is also described. Results of the modified procedures are compared to the NHTSA procedures for a number of late model vehicles.

## INTRODUCTION

Transport Canada in collaboration with the NHTSA, has been for several years, conducting research to ensure that the frontal protection requirements of short stature occupants are addressed in federal regulations. The final rule (NPRM) to amend the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 for Occupant Crash Protection was published in the Federal Register (49 CFR 552) by the NHTSA on May 12, 2000 [1]. As Transport Canada prepares to amend its own CMVSS 208 certain key elements of the NHTSA final rule are being closely examined and evaluated. This includes a review of the procedures for evaluating the low risk requirement of advanced frontal air bags.

The final rule includes two out-of-position static deployment tests using the Hybrid III 5<sup>th</sup> female: Both test procedures are intended to represent worst case conditions for out-of-position short stature occupants. The chin on rim test is meant to maximize loads to the chest while the chin on hub test is intended to maximize loads to the head and neck. Concerns have been expressed as to the

extent to which these objectives would be met by these procedures, at least as implemented by NHTSA [2].

Two recent Canadian airbag fatalities, one involving fatal chest injuries and the other a fatal head/neck injury, provide compelling evidence of the need to establish testing protocols to limit airbag aggressiveness and reduce injury risk to out-of-position (OOP) occupants.

This paper describes on-going efforts undertaken by Transport Canada to evaluate the technical merits of the procedures advanced to date to assess driver injury risk from airbag systems based on static in-vehicle testing.

## BACKGROUND

The NHTSA special investigations have identified 63 drivers killed by airbags in low speed collisions. Within this sample there were 43 serious or fatal chest injuries, 23 head and 9 serious or fatal spinal injuries. Figure 1 illustrates the proportion of chest injuries recorded between June 1991 and January 2001 by vehicle model year. Of the 40 fatally injured drivers with chest injuries, 28 were female.

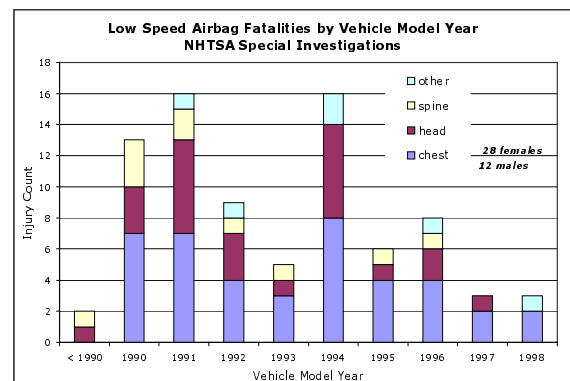


Figure 1. Distribution of low speed airbag fatalities by vehicle model year.

In contrast, there have been 8 confirmed low speed airbag fatalities in Canada since October 1993, 6 of these involving adults, all drivers. The two most recent driver fatalities involved a fatal chest injury and a fatal head and upper neck injury in model year 2000 vehicles.

The fatal chest injury occurred in a 2000 model year Acura Integra. Evidence obtained by the special investigations team indicated that the short stature female driver was seated in the foremost seat track position. The steering wheel was positioned at the lowest setting in the range. Investigators found witness marks corresponding to hairline contact with the windshield and abrasions to the wiper control. Black transfer marks were present on the front central portion of the driver's blouse. Her injuries included a transected aorta, multiple rib fractures and a fractured sternum. There were no head or neck injuries.

The second fatality involved an elderly lady who was wearing her seat belt and who was seated in the forward of mid seat track driver position of a 2000 Oldsmobile Alero. Her vehicle careened down a steep snow covered embankment. The airbag deployed towards the bottom of the embankment when the undercarriage struck a rock. Her injuries were confined almost exclusively to the head and neck and consisted of a diffuse subarachnoid hemorrhage and subluxation of the atlanto-occipital joints with cord contusion. There was no sign of module flap contact to the face or neck region and there were no chest injuries.

## **METHODOLOGY**

### **Vehicle Selection and Preparation**

Static in-vehicle deployments were carried out with a 5<sup>th</sup> percentile Hybrid III anthropomorphic test dummy in the driver seat of model year 2000, production vehicles. The vehicle sample tested consisted of an Acura Integra, an Oldsmobile Alero and 11 vehicle models selected for a separate side impact crash test programme.

Prior to placement of the dummy, test vehicles were leveled, placed in the design attitude and stabilized. Each of the vehicle models selected for this programme was subjected to a minimum of two OOP tests. Deployed airbags were replaced with modules purchased from the respective dealerships. The steering wheel assembly was carefully inspected

after each test. Damaged steering wheel assemblies were either completely replaced or repaired with original replacement parts.

### **Instrumentation and Filtering**

The dummy was instrumented with a tri-axial accelerometer at the head CG, a 6-axis Denton load cell at the upper and lower neck, a linear chest potentiometer, upper and lower sternum accelerometers and tri-axial accelerometers at the upper, mid and lower spine (~T-1/ T-4/ T12). The dummy was grounded and sprayed with anti-static spray before each test. Data recording and filtering was performed in accordance with SAE J211.

### **Documentation of Dummy Position & Motion**

Dummy placement was digitized using the Bronze series FARO arm. The FARO arm is an articulated linkage device with electromechanical sensors at each joint. Absolute accuracy is  $\pm 0.3\text{mm}$  while the practical accuracy is closer to  $\pm 1\text{mm}$  when coordinate transformations are taken into account. Digitized data points included dummy landmarks, reference points on the steering wheel, airbag module, and the centreline of the seat. All points were referenced to the vehicle's fiducial coordinate system. Airbag interaction was filmed with high speed videos at a rate of 1000 frames per second in left and right lateral views orthogonal to the mid-sagittal plane of the dummy. Multiple digital still images were obtained pre and post deployment.

### **Development of Chest on Module Test**

Evaluation of NHTSA's "Chin on Rim" test was initially performed using the Acura Integra as a case study. The Acura, when tested following NHTSA's chin on rim test protocol, yielded a peak chest deflection of only 23.1 mm. This deflection value was judged to be inconsistent with the massive chest injuries incurred by the female driver of the Acura in the collision case noted earlier. An analysis of the dummy response data and video footage suggested that the intensity of the airbag punchout phase experienced by the female victim in the collision was not accurately being represented in the chin on rim test. This was attributed to the fact that the test protocol contained a number of constraints which, collectively, inhibited very close alignment of the chest with the airbag module. The associated constraints included:

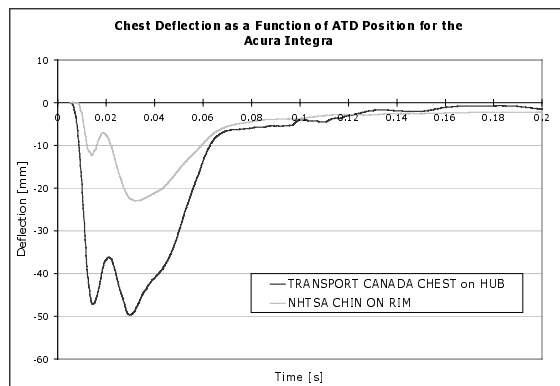
- the requirement that the steering wheel be positioned at the geometric centre of its range;
- the requirement for the thorax to be aligned such that the spine box is inclined at 6 degrees forward of the steering wheel angle;
- the requirement for the centre of the dummy's chin to be placed in contact with the upper rim without pre-loading the neck; and
- the requirement that a minimum clearance of 10 mm between the dummy head and the windshield be maintained.

As the above constraints seemed either arbitrary or counterproductive from the standpoint of achieving a worst case scenario for maximum chest loading, a modified test protocol was developed. The changes included placing the steering wheel in the lowest vertical setting. To facilitate alignment of the chest relative to the steering rim, a 10 cm by 10 cm block of wood is employed under the pelvis of the dummy instead of the usual flat shims or plates. This reduces interference between the thighs and lower rim of the steering wheel and brings the chest into closer alignment with the module. Finally, in order to get the chest closer still, the chin was lifted

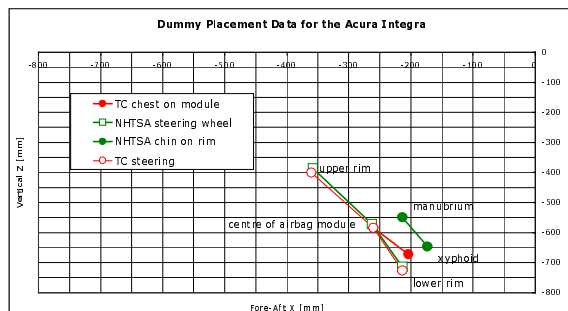
up and over the upper steering rim.

When the Acura Integra was retested following the modified test procedure, a peak chest compression of 49.7 mm was obtained, a value in excess of twice that obtained with the NHTSA chin on rim test (23.1 mm). The modified test procedure also produced transfer marks on the clothing of the dummy from the airbag module doors which matched those observed on the fatally-injured driver's blouse. The abrasions to windshield wiper control arm on the steering column observed in the fatal collision were also replicated. Neither of these transfer marks were reproduced in the NHTSA test.

A comparison of the chest deflection-time histories traces obtained following the modified test procedure with that obtained with the original chin on rim test with the Acura Integra is presented in Figure 2. The first peak represents contact with the module flaps as they open. The second peak deflection corresponds to loading from the airbag. While both traces share general shape characteristics the magnitude of the deflections obtained with the modified test procedure TC test are significantly greater both during the punchout phase and during the airbag expansion phase.



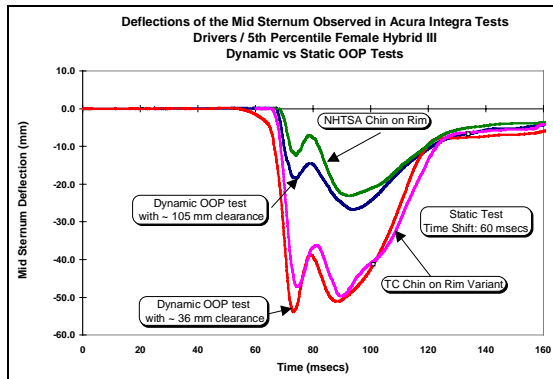
**Figure 2. Chest Deflections: NHTSA Chin On Rim vs. TC Chest On Module.**



**Figure 3. Digitized Data For The Acura Integra Dummy Positions.**

Figure 3 provides a graphical comparison of the digitized positioning data obtained in the two Acura Integra tests. The plot illustrates the difference in steering wheel orientation between the TC and NHTSA procedures and differences in chest position with respect to the airbag module. In the case of the TC modified testing protocol the steering wheel is rotated clockwise and down. The dummy upper chest or manubrium is in direct contact with the center of the airbag module.

As a check to confirm the modified test procedure truly approximates a worst case loading condition with respect to the chest, two dynamic OOP tests of the Acura Integra were performed. In these tests the vehicles impacted a stationary moving deformable barrier (MDB) at 16 km/h to simulate a low speed frontal impact with the back of another vehicle. In these tests, the airbags were set to fire at a predetermined time (60 msec) after the onset of impact. The first test was performed with the clearance between the dummy and steering hub set to approximately 105 mm. The vehicle and dummy response data obtained from the initial dynamic test were used to quantify the clearance required to to achieve contact of the steering wheel by the chest at



**Figure 4. Chest Deflection Comparisons:  
Dynamic vs. Static OOP Tests.**

the moment of bag deployment. This calculated clearance (~36 mm) was employed in the second dynamic test. The objective of achieving dummy contact with the steering module at the moment of airbag deployment was achieved in the second test. A peak chest deflection of 53.9 mm was obtained in the second OOP test. This compares very favourably with the peak chest deflection obtained with the modified static testing protocol (49.7 mm). A comparison of the chest deflection-time histories obtained in the two OOP tests with those obtained earlier in the static tests is presented in Figure 4. As can be seen, the loading pattern obtained with the modified testing procedure compares favourably with that observed in the second dynamic OOP test.

The above findings, together with the crash investigation data, collectively highlight the need to minimize chest clearance in order to accurately assess injury risk in a static airbag deployment test. Referring back to Figure 3, the increased horizontal chest clearance obtained with the NHTSA procedure was approximately 50 mm greater than that produced with the modified test procedure. This relatively small increase in clearance, nevertheless, was sufficient to reduce the peak chest deflection by half.

### TC Chest on Module Test

Drawing on the knowledge gained in the Acura Integra tests, a general atd positioning procedure was defined based on the modified chin on rim test. The name of the procedure was changed to the “Chest on Module” test to more properly reflect the objectives of this test. This procedure is described in detail below.

The steering wheel is adjusted to the lowest possible setting while still maintaining sufficient

clearance for the legs of the dummy. The 5<sup>th</sup> percentile female Hybrid III dummy is positioned in the driver seat with the seat in the rearmost track position to facilitate initial placement. A wooden shim measuring approximately 10 cm by 10 cm and of sufficient length to span the width of the seat is placed underneath the rearmost portion of the dummy pelvis to increase the pelvic tilt. The pelvis is pulled upwards and rearward to rest against the seat back and enhance forward flexion of the thorax. The seat is then brought forward to the foremost track position while holding the chin up to clear the upper rim of the steering wheel. The seat height is adjusted to help align the centre of the sternum with the centre of the airbag module and to minimize the clearance between the chest and the airbag module. In vehicles with seats that do not allow a vertical adjustment, additional ½” thick shims measuring approximately 12 by 12 inches square are stacked beneath the four by four. Placement of the chin over the upper rim of the steering wheel is necessary to increase the proximity of the chest to the module. In vehicles where the space between the upper rim of the steering wheel and the windshield restricts the insertion of the dummy head, the chin was tilted upwards extending the neck rearwards into extension. Contact with the windshield is permitted.

### Evaluation of Chin on Hub Test

To date only 12 static tests, all based on one vehicle, have been performed to evaluate the NHTSA chin on hub test. With the exception of one variant of the chin on hub test, all of the neck loads measured in this initial series of tests were judged to be essentially benign. However, the one variant did produce significantly higher neck loads than was achieved in the baseline chin on module test. While it appears that the NHTSA chin on hub may always represent a worst case condition, far more tests need to be completed before any general conclusions can be made on what would constitute the most appropriate test position to maximize head and neck loads.

### FLEET COMPARISONS

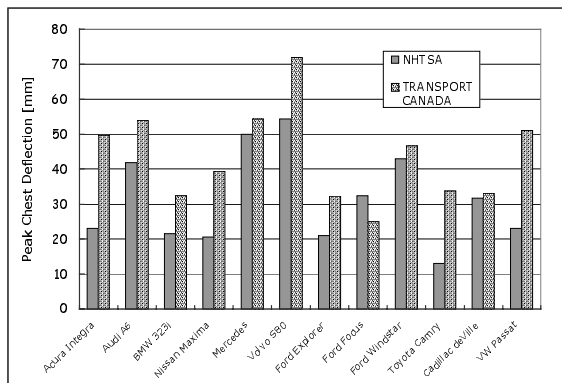
#### Chin on Rim (NHTSA) vs. Chest on Module (TC)

A total of 12 vehicle models were subjected to in-vehicle OOP tests following both the NHTSA chin on rim test protocol and the TC chest on module test protocol. The chest responses measured in this series of paired tests are in Table 1. Graphical

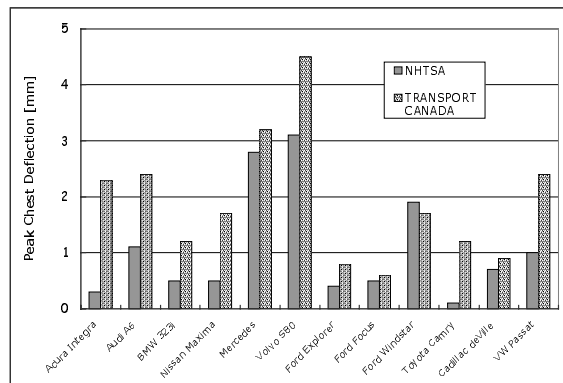
representations of the peak chest deflections and the corresponding peak viscous criterion ( $VC_{max}$ ) values are presented in Figure 5 and Figure 6, respectively.

From the results presented, it can be seen that the peak mid-sternum deflection value obtained with the TC chest on module test exceeded the value obtained with the NHTSA chin on rim test for 11 of

the 12 vehicle models tested. On average, the TC test yielded a peak deflection value 54% greater than that observed in the NHTSA test. The TC test consistently yielded a higher  $VC_{max}$  value for all the vehicle models tested. The  $VC_{max}$  values obtained with the TC procedure were typically of an order of magnitude twice greater than those obtained with the NHTSA procedure.



**Figure 5. Peak Sternal Compression Values: NHTSA vs. Transport Canada.**



**Figure 6. Peak Sternal VC Values NHTSA vs. Transport Canada.**

**Table 1**  
**Summary of Chest Response**

Paired Tests	Nhtsa Chin On Rim	
	Peak Sternum Deflection [mm]	Peak VC
Vehicle Model		
Acura Integra	23.1	
Audi A6	41.8	
BMW 323I	21.5	0.5
Cadillac De Ville	31.7	0.7
Ford Explorer	20.9	0.4
Ford Focus (test 1)	32.3	0.5
Ford Focus (test 2)	28.0	0.3
Ford Windstar	43.0	1.9
Mercedes E320	49.9	2.8
Nissan Maxima	20.6	0.5
Toyota Camry	13.0	0.1
VW Passat	23.1	1.0
Volvo S80	54.3	3.1



**Figure 7. NHTSA Chin On Rim Test - Vehicle With Sufficient Windshield Clearance.**

For some vehicle models, the differences in the chest responses produced with the TC procedure were minimal. In others, they were very pronounced. The magnitude of the difference was influenced largely by the extent to which the clearance between the steering wheel and the chest was reduced following the TC positioning. Figure 7 illustrates the position of the dummy in the NHTSA test vehicle when there is ample head clearance and interference with the windshield is not a problem. The chin can be seen to be nicely aligned with the upper rim of the steering wheel. While there is a triangular gap below the chin, the lower chest is still reasonably close to the steering wheel. In the case of vehicle models such as Cadillac de Ville, the Ford Windstar and the Mercedes, which provide ample head space above

the steering wheel, the peak mid-sternum deflections measured in TC tests were only marginally greater than those measured in the NHTSA tests.

Figure 8, illustrates a typical NHTSA position where contact with the windshield prevents the dummy chin from being aligned with the upper steering wheel rim. This results in the chest being positioned well away from the airbag module. Figure 9 illustrates the position of the dummy in the same vehicle when following the TC procedure. Lowering the steering wheel permits the head to be brought up and over the steering wheel and allows the chest to be placed in close proximity to the airbag module.



The seating position shown in Figure 9 appears exaggerated and unrealistic. This is largely due to dummy characteristics since the dummy is stiff and lacks the joint motion and flexibility of a human. In all of the vehicles included in the sample, a live female test subject of 5<sup>th</sup> percentile stature was able to readily wrap herself around the steering wheel without any contortions.



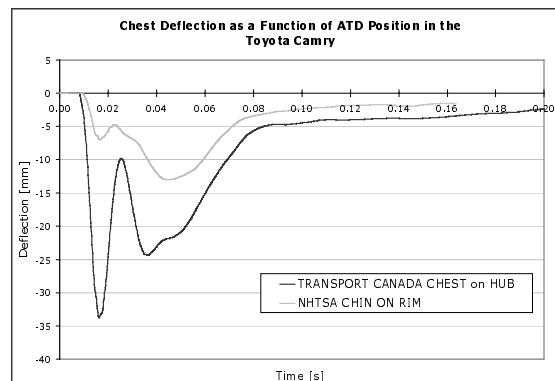
**Figure 9. TC Chest On Module Test - Vehicle With Limited Windshield Clearance.**

Figure 10 illustrates the differences in dummy positioning as a function of test procedure that can be expected in vehicles where there limited windshield clearance and the steering wheel is adjustable. The reduced clearance between the chest and steering assembly achieved with the TC procedure is clearly evident. Moreover, the chest is now centered over the airbag module. This, in combination with the greatly reduced chest clearance, resulted in a dramatic increase the level of chest compression observed in the TC test. A comparison of the deflection plots is presented in



**Figure 8. NHTSA Chin On Rim Test - Vehicle With Limited Windshield Clearance.**

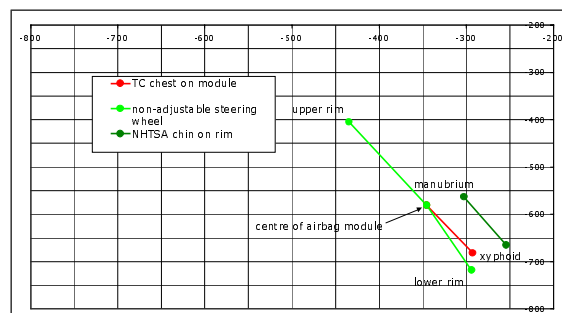
**Figure 11.**



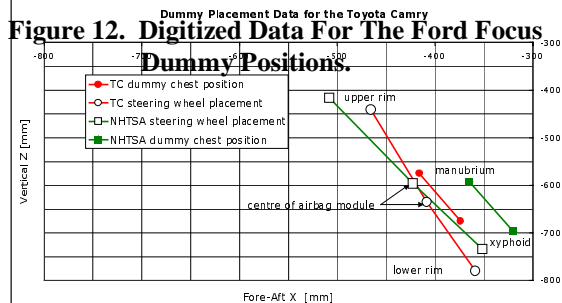
**Figure 11. Chest Deflection Trace For The Toyota Camry.**

From the results presented in Figure 11 it can be observed that maximum chest compression in the TC test occurred during the airbag punchout phase. This loading phase is negligible in the NHTSA test since the chest was far removed from the airbag module cover.

The only vehicle model which produced a higher chest deflection in the NHTSA test than in the TC test was the Ford Focus. When the Ford Focus tests were repeated, equivalent peak deflections and VC values were recorded for both the NHTSA and the TC tests.



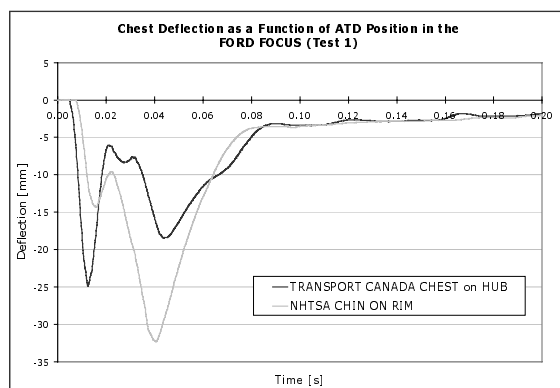
**Figure 12. Digitized Data For The Toyota Camry Dummy Positions.**



**Figure 10. Digitized Data For The Ford Focus Dummy Positions.**

Figure 12 depicts the difference in position for the Ford Focus test as defined by the digitized data. In this case the steering wheel is not adjustable so the only difference is the proximity of the chest to the module. In the TC position, the manubrium of the dummy is in contact with the centre of the module while the NHTSA procedure places the dummy manubrium approximately 100 mm away from the module.

Figure 13 is the chest deflection trace obtained for the first test series on the Ford Focus. The TC trace demonstrates the expected rapid onset loading during the airbag punchout phase. Maximum compression of the chest occurs during this phase of deployment. Due to the increased chest clearance in the NHTSA test, there is negligible loading of the chest during the punchout phase. In the NHTSA test, maximum chest compression occurs later during the airbag expansion phase of deployment.



**Figure 13. Chest Deflection Trace For A Ford Focus (Test 1).**

A review of the high speed videos suggests that the Ford Focus airbag behaves differently when obstructed than when not obstructed. In both TC test configurations, the airbag appears to have difficulty unfolding and remains high on the chest while it competes for space around the steering wheel. In the NHTSA tests, the increased chest clearance allows the airbags to open instantaneously and expand more quickly.

## DISCUSSION

Static OOP tests of frontal airbags can serve as a useful complement to in-position dynamic belted testing, even in jurisdictions such as Canada where high belt wearing rates predominate. Although sometimes viewed as representing an unbelted test

condition, it is important to recognize that there are situations which can result in a belted driver being placed in a position where he or she is in very close or even direct contact with the airbag module at time of deployment. Indeed, the first recorded bag-related female adult fatality in Canada involved a belted driver who was slumped over the steering wheel at the time of collision.

In order to be of practical value in reducing the incidence of bag-related injury, the OOP test condition must, by necessity, be designed to replicate the “worst case” scenario which can reasonably be expected to occur in the field. The interaction monitored in the test must also be field relevant in terms of the associated injury mechanism. From the standpoint of assessing injury risk to the chest under OOP conditions, an essential requirement is that the potential loads applied to the occupant during the airbag punchout phase of airbag deployment be accurately represented in the OOP test. This can only be accomplished by ensuring the clearance between the chest and airbag module is kept to the absolute minimum. Based on the evidence collected to date, the TC chest on module test provides a more stringent means of assessing OOP chest injury risk than is provided by the current chin on rim test specified by NHTSA.

Several of the constraints imposed by the chin on rim procedure appear to have been motivated by the desire to minimize any hooking or pre-loading of the neck of the dummy so as to allow neck loads to be monitored during the test. The TC procedure can result in the pre-loading of the neck. However, the practical value of monitoring neck loads in a test which is designed to maximize chest loads is dubious, particularly when the precautions taken, adversely affect the primary objective of the test. It would seem far more preferable to monitor only chest loads in tests designed to maximize chest loads, and only neck loads in tests designed to maximize neck loads. Clearly, if each test protocol achieves its own stated objective, then there is no added advantage to monitoring responses in the other body region.



## **ACKNOWLEDGMENTS**

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The opinions expressed and conclusions reached in this paper are solely the responsibility of the authors and do not necessarily represent the official policy of Transport Canada.

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